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Effects of feeding varying ingredient particle sizes and diet forms for 25- to 50-lb nursery pigs on performance, caloric efficiency, and economics

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Abstract

A total of 675 pigs (PIC 1050 barrows; initially 24.5 lb BW and 37 d of age) were used in a 21-d study to determine the effects of feeding varying ingredient particle sizes and diet form for 25- to 50-lb nursery pigs on performance, caloric efficiency, and economics. Pens of pigs were balanced by initial BW and randomly allotted to 1 of 8 dietary treatments with 17 replications per treatment and 5 pigs per pen in two groups of nursery pigs. The 8 experimental diets included 3 corn-soybean mealâ€“based diets consisting of: (1) corn fraction ground to an average of 620 Î¼ and fed in meal form, (2) corn fraction ground to an average of 352 Î¼ and fed in meal form, and (3) diet 2 but pelleted. The remaining 5 diets were high by-product diets containing 20% wheat middlings (midds) and 30% dried distillers grains with solubles (DDGS). Diets 4 to 8 consisted of: (4) corn fraction ground to an average of 620 Î¼, midds and DDGS unground from the plant with an average particle size of 534 Î¼ and 701 Î¼, respectively, and fed in meal form; (5) diet 4 but corn fraction ground to an average of 352 Î¼ and fed in meal form; (6) diet 5 but fed in pellet form; (7) corn, soybean meal, DDGS, and midds ground to average particle sizes of 352 Î¼, 421 Î¼, 377 Î¼, and 357 Î¼, respectively, fed in meal form; and (8) diet 7 but fed in pellet form. The two formulated diets were not balanced for energy, so energy was lower for treatments 4 to 8 than for treatments 1 to 3.; Swine Day, Manhattan, KS, November 15, 2012

Keywords

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Effects of Feeding Varying Ingredient Particle Sizes and Diet Forms for 25- to 50-lb Nursery Pigs on Performance, Caloric Efficiency, and Economics[1,2]

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Summary

A total of 675 pigs (PIC 1050 barrows; initially 24.5 lb BW and 37 d of age) were used in a 21-d study to determine the effects of feeding varying ingredient particle sizes and diet form for 25- to 50-lb nursery pigs on performance, caloric efficiency, and economics. Pens of pigs were balanced by initial BW and randomly allotted to 1 of 8 dietary treatments with 17 replications per treatment and 5 pigs per pen in two groups of nursery pigs. The 8 experimental diets included 3 corn-soybean meal–based diets consisting of: (1) corn fraction ground to an average of 620 µ and fed in meal form, (2) corn fraction ground to an average of 352 µ and fed in meal form, and (3) diet 2 but pelleted. The remaining 5 diets were high by-product diets containing 20% wheat middlings (midds) and 30% dried distillers grains with solubles (DDGS). Diets 4 to 8 consisted of: (4) corn fraction ground to an average of 620 µ, midds and DDGS unground from the plant with an average particle size of 534 µ and 701 µ, respectively, and fed in meal form; (5) diet 4 but corn fraction ground to an average of 352 µ and fed in meal form; (6) diet 5 but fed in pellet form; (7) corn, soybean meal, DDGS, and midds ground to average particle sizes of 352 µ, 421 µ, 377 µ, and 357 µ, respectively, fed in meal form; and (8) diet 7 but fed in pellet form. The two formulated diets were not balanced for energy, so energy was lower for treatments 4 to 8 than for treatments 1 to 3.

Overall (d 0 to 21), pigs fed pelleted diets had improved ($P < 0.03$) ADG, F/G, and caloric efficiency when measured on an ME or NE basis. Reducing the particle size of the corn did not influence F/G or caloric efficiency, but tended ($P < 0.08$) to reduce ADFI, which led to a reduction ($P < 0.02$) in ADG. Pigs fed the high-by-product diet had reduced ($P < 0.001$) ADG, ADFI, and final BW and poorer ($P < 0.01$) F/G, but caloric efficiency similar to pigs fed the corn-soybean meal–based diet. Grinding the by-products to a smaller particle size further reduced ($P < 0.05$) ADG, ADFI, and final BW but did not influence feed efficiency.

For economics, although feed cost per pig tended to decrease ($P < 0.09$) when corn was finely ground or when all ingredients were finely ground, it was reduced ($P < 0.0001$) enough only for pigs fed the high-by-product diet to result in a reduction ($P < 0.001$) in feed cost per pound of gain. Because of reduced total revenue per pig, pigs fed

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[2] Appreciation is expressed to Spencer Lawson and the Kansas State University Grain Science Feed Mill for technical support.

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high-by-product diets had income over feed cost (IOFC) similar to pigs fed the corn-soybean meal–based diet. Fine-grinding all feed ingredients also decreased ($P < 0.0001$) revenue/pig and IOFC. Pelleting was the only processing technology that improved ($P < 0.01$) revenue/pig and IOFC in this trial. Grinding corn finer than 620 µ or grinding other components of the high-by-product diet did not improve nursery pig performance or IOFC; however, pelleting resulted in the expected improvements in pig performance and economic return.

Key words: DDGS, feed processing, nursery pig, wheat middlings

Introduction

Increasing ingredient costs have resulted in swine producers searching for low-priced energy sources to replace corn in diets. Wheat middlings and corn DDGS are both common high-fiber (midds, crude fiber <9.5%; DDGS, crude fiber = 7.3%) by-products of the wheat milling and ethanol industries, respectively. With corn currently trading around $8.00/bu, these two ingredients have become common additions to many swine diets to help lower feed costs. Although traditional DDGS with a fat content greater than 10% has an energy value similar to corn, midds have a lower energy concentration (ME = 1,372 kcal/lb; NRC, 1998[5]).

Processing of individual ingredients or complete diets can provide alternative methods to more efficiently utilize dietary energy from cereal grains or other feedstuffs. Grinding corn from 900 to 300 µ in early nursery phases has been shown to improve ADG, ADFI, and F/G[6]. Pelleting of diets also has been found consistently to improve ADG and F/G, but research evaluating fine-grinding of fibrous feed ingredients or grinding of all major ingredients fed in the same diet has been limited; therefore, the objective of this study was to determine the effects of feeding various ingredient particle sizes and diet forms on growth performance, caloric efficiency, and economics of nursery pigs from 25 to 50 lb.

Procedures

The protocol for this experiment was approved by the Kansas State University Institutional Animal Care and Use Committee. The study was conducted at the K-State Segregated Early Weaning Facility in Manhattan, KS.

A total of 675 pigs (PIC 1050 barrows; initially 24.5 lb BW and 37 d of age) were used in a 21-d study. Pigs were allotted to pens by initial BW, and pens were assigned to treatments in a completely randomized design with 5 pigs per pen and 17 replications per treatment. Two groups of pigs were used with 8 replications in one group and 9 replications in the second group. The two formulated diets included a corn-soybean meal–based control diet and a negative control diet containing 20% midds and 30% DDGS (Table 1). The 8 experimental diets included the corn-soybean meal–based diets with: (1) corn fraction ground to an average of 620 µ and diet fed in meal form, (2) corn fraction ground to an average of 352 µ and diet fed in meal form, and (3) diet 2 but pelleted. The remaining 5 diets were the high-by-product diet with treat-

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[5] NRC. 1998. Nutrient Requirements of Swine, 10th ed. Natl. Acad. Press, Washington DC.

[6] Healy, B. J. 1994. Optimum particle size of corn and hard and soft sorghum for nursery pigs. J. Anim. Sci. 72:2227.

ments consisting of: (4) corn fraction ground to an average of 620 µ, midds and DDGS unground from the plant with an average particle size of 534 and 701 µ, respectively, and diet fed in meal form; (5) diet 4 but corn fraction ground to an average of 350 µ and fed in meal form; (6) diet 5 but fed in pellet form; (7) corn, soybean meal, DDGS, and midds ground to average particle sizes of 352, 421, 377, and 357 µ, respectively, fed in meal form; and (8) diet 7 fed in pellet form. For diet formulation, the ME value of DDGS was similar to that of corn (1,551 kcal/kg; NRC 1998[5]), whereas the midds ME value was 1,372 kcal/lb (NRC, 1998). Diets were not formulated on an energy basis, so diet energy was lower for high-by-product treatment diets. All diets were formulated to a constant standardized ileal digestible (SID) lysine level to ensure changes in performance were due to dietary energy differences rather than differences in amino acid concentrations.

Feed was manufactured separately for each group of pigs. For the first group, all ingredients were ground and complete diets were manufactured (meal and pellets) at the K-State Grain Science Feed Mill. For the second group, all ingredients were ground and complete diets were manufactured (meal) at the K-State Grain Science Feed Mill; diets requiring pelleting were transported to Hubbard Feeds (Beloit, KS) for processing. All 620-µ corn was ground by a 3-high roller mill (Model TP 912, Roskamp Manufacturing, Cedar Falls, IA). All ingredients that were finely ground were processed using a full-circle teardrop hammermill (P-240D Pulverator, Jacobsen Machine Works, Minneapolis, MN) with a 1/16-in. screen. Diets for the first group of pigs were pelleted in a 30-horsepower pellet mill (30 HD Master Model, California Pellet Mill, San Francisco) with a 1.25-in.-thick die with 5/32-in. openings. Pellets from the second group were made with an Ace 50, Sprout Waldron Pellet Mill with 11/64-in. openings. Corn was from the same source for both groups of pigs and was split at the mill to be ground through the hammermill or roller mill.

Pigs were provided unlimited access to feed and water by way of a 4-hole dry self-feeder and a cup waterer in each pen (5 ft × 5 ft). Pig weight and feed disappearance were measured on d 0, 7, 14, and 21 of the trial to determine ADG, ADFI, and F/G.

Samples of corn, soybean meal, midds, DDGS, and complete diets were collected and submitted to Ward Laboratories, Inc. (Kearney, NE) for analysis of DM, CP, ADF, NDF, crude fiber, fat, ash, Ca, and P (Tables 2 and 3). In addition, bulk density and particle size of the corn, soybean meal, midds, DDGS, and complete diets were determined. Angle of repose for all ingredients and diets in meal form was also determined. For all diets in pelleted form, pellet durability index (PDI), percentage fines, production rate, and hot pellet temperature were obtained (Table 4).

Caloric feed efficiencies were determined on both an ME and NE (INRA, 2004[7]) basis. Efficiencies were calculated by multiplying total feed intake × energy in the diet (kcal/lb) and dividing by total gain. Lastly, feed cost/pig, feed cost/lb gain, revenue/pig, and IOFC were also calculated. Diet costs were determined with the following ingredient costs: corn = $8.00/bu, soybean meal = $480/ton, midds = $240/ton, and DDGS = $280/ton. Processing costs were as follows: grinding = $5/ton, mixing = $3/ton,

[7] INRA (Institut National de la Recherche Agronomique). 2004. Tables of composition and nutritional value of feed materials, Sauvant, D., J-M. Perez and G. Tran, Eds. Wageningen Academic Publishers, The Netherlands and INRA, Paris, France.

delivery and handling = $7/ton, and pelleting = $6/ton. Feed cost/pig was determined by total feed intake × diet cost ($/lb). Feed cost/lb gain was calculated using F/G × diet cost ($/lb). Revenue/pig was determined by total gain × $0.65/lb live gain, and IOFC was calculated using revenue/pig – feed cost/pig.

Data from both groups were combined and analyzed as a completely randomized design using the PROC MIXED procedure of SAS (SAS Institute, Inc., Cary, NC) with pen as the experimental unit. Treatment was considered a fixed effect and group as a random effect in the statistical model. Contrasts were used to compare the effects of diet form, corn particle size, diet type (corn soybean meal vs. high by-product), and grinding of all ingredients. Results were considered significant at $P \leq 0.05$ and a trend at $P \leq 0.10$.

Results and Discussion

The chemical analyses of the midds, DDGS, soybean meal (SBM), and corn (Table 2) revealed that most nutrients were similar to formulated values. Crude protein was slightly lower for DDGS and SBM than formulated values. Crude fiber levels were lower for midds and SBM but slightly higher for DDGS and corn than formulated values. All ingredients were slightly higher for Ca and P than formulated values. As expected, analysis of the dietary treatments showed increased fiber component levels with the addition of increasing midds and DDGS to the diet. The diet bulk density also decreased when by-products were added to the diet. When similar diets were pelleted, bulk density increased. Angle of repose increased as corn or all ingredients were finely ground, and PDI increased as ingredients were finely ground and by-products were added to the diet. The percentage of fines decreased as ingredients were finely ground and by-products were added to the diet.

Overall (d 0 to 21), pigs fed pelleted diets had improved ($P < 0.03$) ADG, F/G, and caloric efficiency when measured on an ME or NE basis. Reducing the particle size of the corn did not influence F/G or caloric efficiency, but tended ($P < 0.08$) to reduce ($P < 0.08$) ADFI, which led to a reduction ($P < 0.02$) in ADG. Pigs fed the high-by-product diet had reduced ($P < 0.001$) ADG, ADFI, and final BW and poorer ($P < 0.01$) F/G but caloric efficiency similar to pigs fed the corn-SBM–based diet. Grinding the by-products to a smaller particle size further reduced ($P < 0.05$) ADG, ADFI, and final BW but did not influence feed efficiency.

In the economic analysis, although feed cost per pig tended to decrease ($P < 0.09$) when corn was finely ground or when all ingredients were finely ground, it was reduced ($P < 0.0001$) enough only for pigs fed the high-by-product diet to result in a reduction ($P < 0.001$) in feed cost per pound of gain. Because of reduced total revenue per pig, pigs fed high-by-product diets had IOFC similar to pigs fed the corn-SBM–based diet. Fine-grinding all feed ingredients also decreased ($P < 0.0001$) revenue/pig and IOFC. Pelleting was the only processing technology that improved ($P < 0.01$) revenue/pig and IOFC in this trial.

Results from this study suggest that reducing the particle size of either corn or all major ingredients in complete feed when fed in meal form decreased performance in nursery pigs. This result was unexpected. Previous research has consistently shown improvements in feed efficiency as corn particle size is reduced, and reasons for this finding in our study are unknown. Interestingly, as all major ingredients were ground in the high-by-product diet and fed in meal form, feed intake for these pigs was clearly the lowest of all pigs fed diets in meal form, which suggests that feeding a finely ground complete diet may have reduced palatability. Feeders were checked frequently to ensure pigs had ad libitum access to feed and that the ADFI response was not due to feed bridging in feeders.

As expected, pelleting diets in this study improved growth rate, feed efficiency, and caloric efficiency. This improvement could be due to improvements in diet digestibility, because feed intake was not changed. The study also showed that pelleting increased total revenue and IOFC when using a pelleting charge of $6/ton. Numerically, the highest IOFC occurred for treatment 3 (finely ground corn without by-products and pelleted diet).

Fine-grinding resulted in decreased growth rate through reduced feed intake. These data confirm the growth performance benefits of pelleting diets for nursery pigs. In addition, fine-grinding all major ingredients in a high-by-product diet did not improve performance and led to reduced economic returns due to higher processing costs and lack of benefit in growth.

Table 1. Diet composition (as-fed basis)[1]

	DDGS, %:[2]	0	30
Item	Midds, %:	0	20
Ingredient, %			
Corn		63.69	24.59
Soybean meal (46.5% CP)		32.80	22.43
DDGS		---	30.00
Wheat middlings		---	20.00
Monocalcium phosphate (21% P)		1.05	0.05
Limestone		1.00	1.50
Salt		0.35	0.35
Vitamin premix		0.25	0.25
Trace mineral premix		0.15	0.15
L-lysine HCl		0.33	0.48
DL-methionine		0.135	0.005
L-threonine		0.125	0.075
Phytase[3]		0.125	0.125
Titanium[4]		---	---
Total		100.00	100.00

continued

Table 1. Diet composition (as-fed basis)[1]

	DDGS, %:[2]	0	30
Item	Midds, %:	0	20
Calculated analysis			
Standard ileal digestible (SID) amino acids, %			
Lysine		1.28	1.28
Isoleucine:lysine		61	64
Leucine:lysine		129	152
Methionine:lysine		34	28
Met & Cys:lysine		58	58
Threonine:lysine		63	63
Tryptophan:lysine		17.5	17.5
Valine:lysine		68	76
Total lysine, %		1.42	1.46
ME, kcal/lb[5]		1,503	1,476
NE. kcal/lb[6]		1,072	1,036
SID lysine:ME, g/Mcal		3.86	3.93
CP, %		21.1	24.4
Crude fiber, %		2.7	2.8
NDF, %		4.1	9.9
ADF, %		1.6	4.1
Ca, %		0.70	0.70
P, %		0.63	0.63
Available P, %		0.42	0.42

[1] Treatment diets fed for 21 d.
[2] DDGS: dried distillers grains with solubles.
[3] Phyzyme 600 (Danisco Animal Nutrition, St. Louis, MO) provided 340.5 phytase units (FTU)/lb, with a release of 0.12% available P.
[4] Titanium was included in diets fed from day 7 to 14 in group 1 at a level of 0.4%, at the expense of corn.
[5] NRC. 1998. Nutrient Requirements of Swine, 10th ed. Natl. Acad. Press, Washington DC.
[6] INRA (Institut National de la Recherche Agronomique). 2004. Tables of composition and nutritional value of feed materials, Sauvant, D., J-M. Perez and G. Tran, Eds. Wageningen Academic Publishers, The Netherlands and INRA, Paris, France

Table 2. Chemical analysis of wheat middlings and dried distillers grains with solubles (DDGS; as-fed basis)[1]

Item	Wheat middlings	DDGS	Soybean meal	Corn
DM, %	89.73[2]	90.34	89.89	88.22
CP, %	15.7(15.9)	22.3(27.2)	44.8(46.5)	9.3(8.50)
ADF, %	10.7	13.0	7.0	3.7
NDF, %	32.0	27.8	10.9	11.7
Crude fiber, %	6.6(7.0)	7.7(7.3)	4.2(3.9)	2.3(2.2)
NFE, %[3]	56.6	43.5	34.2	71.0
Ca, %	0.14(0.12)	0.06(0.03)	0.28(0.03)	0.09(0.03)
P, %	1.08(0.93)	0.85(0.71)	0.79(0.69)	0.37(0.28)
Fat, %	3.8	9.9	1.5	3.3
Ash, %	5.1	4.3	6.6	1.7

[1] Values in parentheses indicate those used in diet formulation.
[2] All values are averages of the two groups.
[3] NFE: nitrogen-free extract.

Table 3. Chemical analysis of diets (as-fed basis)[1]

Diet:[2]	Control			HBP				
Ingredient processed:[3]	---	Corn	Corn	---	Corn	Corn	Diet	Diet
Item / Diet form:	Meal	Meal	Pellet	Meal	Meal	Pellet	Meal	Pellet
DM, %	89.38[4]	89.51	89.12	90.54	90.38	89.16	90.53	88.95
CP, %	21.5	21.2	21.6	25.8	24.9	25.0	25.7	25.7
ADF, %	3.8	3.6	4.1	8.5	7.8	7.4	7.7	7.9
NDF, %	7.0	7.4	7.3	19.3	18.2	17.4	17.4	17.8
Crude fiber, %	2.0	2.2	2.2	5.2	5.0	4.7	4.7	4.8
NFE, %[5]	57.5	58.4	56.9	47.4	49.2	48.2	47.9	47.1
Ca, %	0.72	0.72	0.61	0.70	0.53	0.57	0.67	0.75
P, %	0.62	0.60	0.61	0.72	0.71	0.68	0.69	0.71
Fat, %	1.9	1.9	1.9	4.6	3.7	3.8	4.3	3.8
Ash, %	5.6	5.2	5.5	6.1	6.4	6.4	6.4	6.2

[1] A composite sample consisting of 6 subsamples was used for analysis.
[2] Control diet was a corn-soybean meal–based diet; high-by-product diet (HBP) consisted of a corn-soybean meal base with 30% DDGS and 20% wheat middlings.
[3] Ingredients were processed separately through a hammer mill using a 1/16-in. screen. Average particle sizes for ingredients before and after grinding were: corn = 620 and 352 μ; soybean meal = 889 μ and 421 μ; DDGS = 701 μ and 377 μ; midds =534 μ and 357 μ, respectively.
[4] All values are averages of the two groups.
[5] NFE: nitrogen-free extract.

Table 4. Chemical analysis

	Diet:[1]	Control			HBP				
	Ingredient processed:[2]	---	Corn	Corn	---	Corn	Corn	Diet	Diet
Item	Diet form:	Meal	Meal	Pellet	Meal	Meal	Pellet	Meal	Pellet
Particle size, µ		696[3]	517	---	679	551	---	397	---
Bulk density, lb/bu		55.9	58.4	60.2	42.9	45.4	52.8	45.2	54.4
Angle of repose, °		47.4	53.0	---	48.1	52.3	---	54.9	---
Standard pellet durability index		---	---	93.6	---	---	95.4	---	96.8
Modified pellet durability index		---	---	90.4	---	---	93.7	---	95.7
Fines, %		---	---	1.2	---	---	1.1	---	0.7
Production rate, lb/h		---	---	3194	---	---	2787	---	2781
Hot pellet temperature, °F		---	---	177	---	---	177	---	181

[1] Control diet was a corn-soybean meal–based diet; high-by-product diet (HBP) consisted of a corn-soybean meal base with 30% DDGS and 20% wheat middlings.
[2] Ingredients were processed separately through a hammer mill using a 1/16-in. screen. Average particle sizes for ingredients before and after grinding were: corn = 620 and 352 µ; soybean meal = 889 µ and 421 µ; DDGS = 701 µ and 377 µ; midds = 534 µ and 357 µ, respectively.
[3] All values are averages of the two groups.

Table 5. Effects of feeding varying particle sizes and diet forms on 25- to 50-lb nursery pig performance[1]

	Treatment:	1	2	3	4	5	6	7	8					
	Diet:[2]	Control			HBP						Probability, *P*<			
	Ingredient processed:[3]	---	Corn	Corn	---	Corn	Corn	Diet	Diet					
Item	Diet form:	Meal	Meal	Pellet	Meal	Meal	Pellet	Meal	Pellet	SEM	Diet form[4]	Corn µ[5]	Diet[6]	Grinding[7]
d 0 to 21														
ADG, lb		1.43	1.37	1.36	1.29	1.24	1.32	1.21	1.26	0.05	0.03	0.02	<0.001	0.05
ADFI, lb		2.21	2.12	2.09	2.06	2.02	2.00	1.90	1.96	0.09	0.89	0.08	<0.001	0.02
F/G		1.55	1.55	1.54	1.60	1.63	1.52	1.57	1.56	0.02	0.004	0.32	0.01	0.51
Caloric efficiency[8]														
ME		2323	2331	2307	2360	2409	2247	2320	2298	34.4	0.004	0.33	0.44	0.51
NE		1658	1663	1647	1656	1691	1577	1628	1613	24.7	0.004	0.33	0.38	0.51
Wt, lb														
d 0		24.5	24.5	24.5	24.5	24.5	24.5	24.5	24.5	0.35	0.95	0.99	0.99	0.93
d 21		54.7	53.4	54.4	51.6	51.4	52.5	49.4	51.0	51.3	0.06	0.37	<0.001	0.03

[1] A total of 675 pigs (PIC 1050, initially 24.5 lb BW and 37 d of age) were used in a 21-d growth trial with 5 pigs per pen and 17 pens per treatment.
[2] Control was a corn-soybean meal–based diet; high-by-product diet (HBP) consisted of a corn-soybean meal base with 30% dried distillers grains with solubles (DDGS) and 20% wheat middlings.
[3] Ingredients were processed separately through a hammer mill using a 1/16-in. screen. Average particle sizes for ingredients before and after grinding were: corn = 620 and 352 µ; soybean meal = 889 µ and 421 µ; DDGS = 701 µ and 377 µ; midds = 534 µ and 357 µ, respectively.
[4] Treatments 2, 5, and 7 vs. 3, 6, and 8.
[5] Treatments 1 and 4 vs. 2 and 5.
[6] Treatments 1, 2, and 3 vs. 4, 5, and 6.
[7] Treatments 5 and 6 vs. 7 and 8.
[8] Caloric efficiency is expressed as kcal/lb gain.

Table 6. Effects of feeding varying particle sizes and diet form on 25- to 50-lb nursery pig performance[1]

Diet:[2]	Control			HBP						Probability, $P<$			
Ingredient processed:[3]	---	Corn	Corn	---	Corn	Corn	Diet	Diet		Diet			
Item / Diet form:	Meal	Meal	Pellet	Meal	Meal	Pellet	Meal	Pellet	SEM	form[4]	Corn μ[5]	Diet[6]	Grinding[7]
d 0 to 21													
Feed cost/pig, $	8.68	8.35	8.35	7.20	7.07	7.13	6.70	7.05	0.337	0.19	0.07	<.0001	0.09
Feed cost/lb gain, $[8]	0.29	0.29	0.29	0.27	0.27	0.26	0.26	0.27	0.004	0.24	0.31	<.0001	0.87
Total revenue/pig, $[9,10]	19.59	18.77	19.46	17.59	17.46	18.23	16.16	17.22	0.792	0.01	0.25	<.0001	0.01
IOFC[11]	10.91	10.42	11.11	10.39	10.39	11.11	9.45	10.17	0.494	0.01	0.49	0.52	0.01

[1] A total of 675 pigs (PIC 1050, initially 24.5 lb BW and 37 d of age) were used in a 21-d growth trial with 5 pigs per pen and 17 pens per treatment.
[2] Control was a corn-soybean meal–based diet; high-by-product diet (HBP) consisted of a corn-soybean meal base with 30% DDGS and 20% wheat middlings.
[3] Ingredients were processed separately through a hammer mill using a 1/16-in. screen. Average particle sizes for ingredients before and after grinding were: corn = 620 and 352 μ; soybean meal = 889 μ and 421 μ; DDGS = 701 μ and 377 μ; midds =534 μ and 357 μ, respectively.
[4] Treatments 2, 5, and 7 vs. 3, 6, and 8.
[5] Treatments 1 and 4 vs. 2 and 5.
[6] Treatments 1, 2, and 3 vs. 4, 5, and 6.
[7] Treatments 5 and 6 vs. 7 and 8.
[8] Feed cost/lb gain = feed cost/lb × F/G, assumed grinding = $5/ton; mixing = $3/ton; delivery and handling = $7/ton; pelleting $6/ton.
[9] One pound of live gain was considered to be worth $0.65.
[10] Total revenue/pig = total gain/pig × $0.65.
[11] Income over feed cost = total revenue/pig – feed cost/pig.